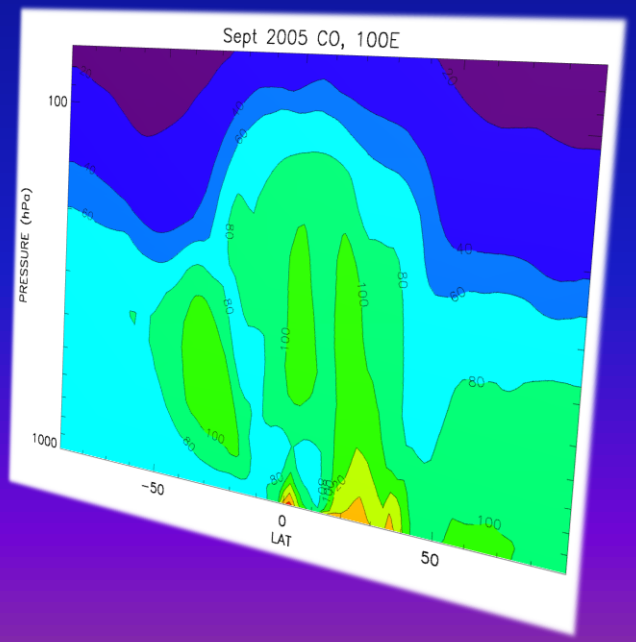
CO in the Upper Troposphere and Lowermost Stratosphere

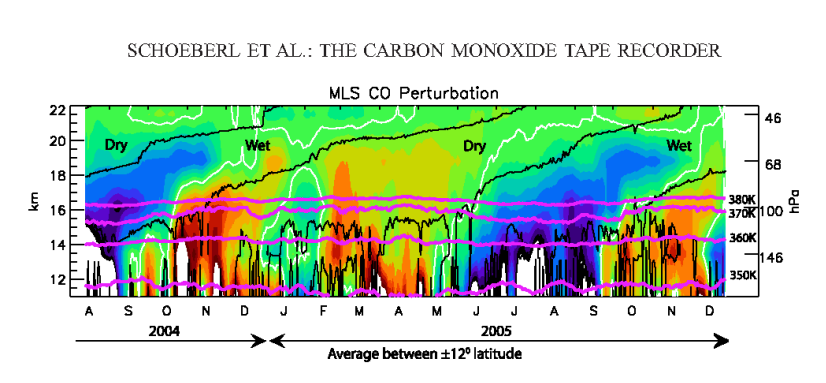
- *Seasonally varying transport, chemistry, and sources*
- *Application to model evaluation*

Susan E. Strahan
University of Maryland, Baltimore County
NASA Goddard Space Flight Center



The basic story of CO

- CO is a tropospheric source gas
- CO is high near the surface and decreases with altitude due to reaction with OH (lifetime of ~months)
- Its sources vary with latitude, longitude, and season
- Strong biomass burning sources are found near the tropics in NH spring and in SH spring
- This leads to a CO 'tape recorder' in the tropical UT and LS



By ~20 km the signal from tropospheric sources is gone.

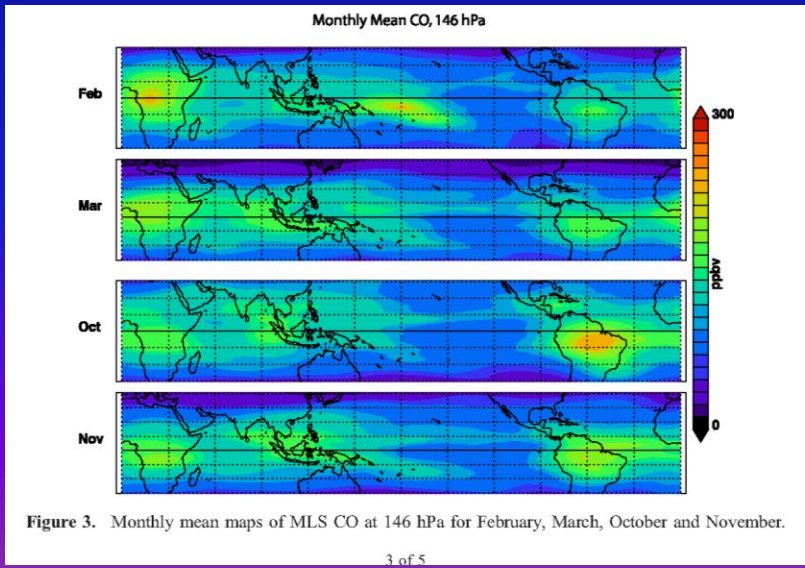
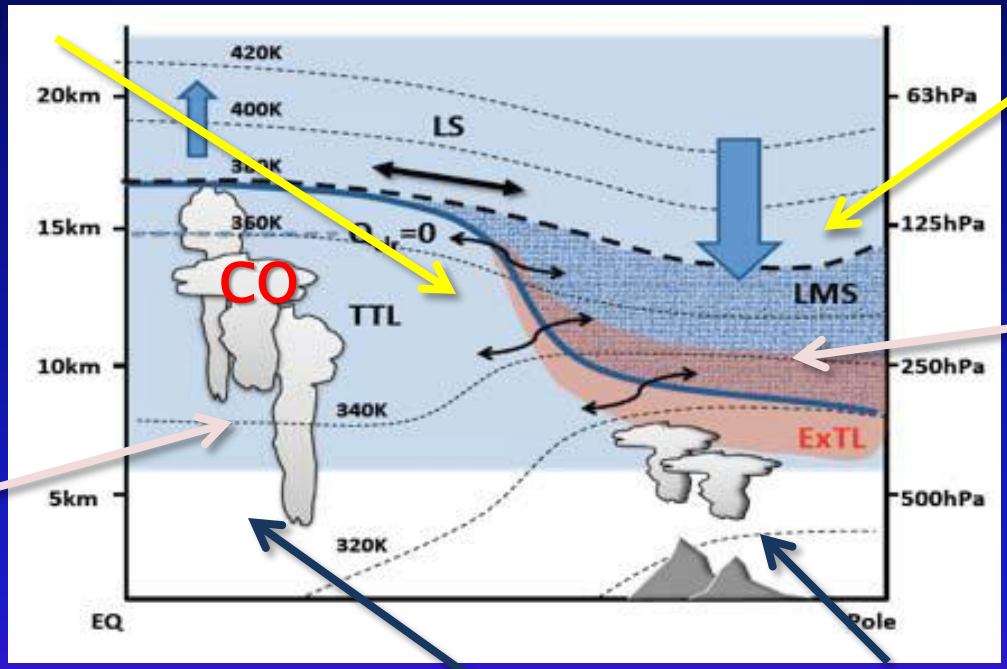


Figure 3. Monthly mean maps of MLS CO at 146 hPa for February, March, October and November.

CO: what happens between the surface and the LS

Quasi-horizontal transport from UT to LMS (strongest in summer and fall

Downward branch of the Brewer Dobson circulation (strongest in winter and spring) – low CO air



Photochemical losses (spring through summer)

Seasonally varying convection, monsoons

CO surface sources (biomass burning, fossil fuels)

Figure from Chapter 7 (Gettelman and Hegglin), SPARC CCMVal Report, 2010

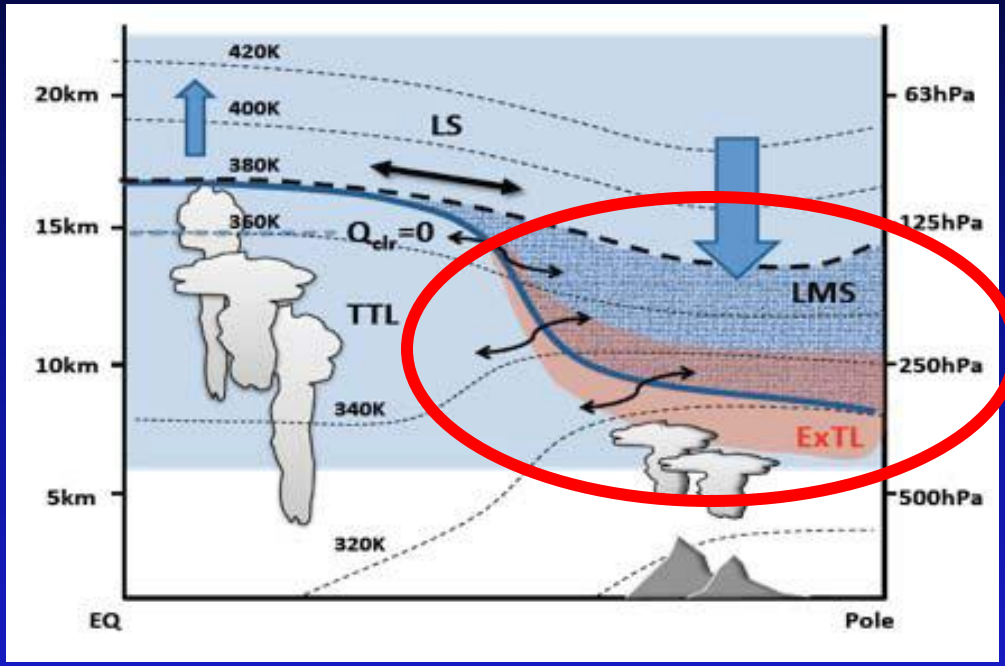
Analysis of CO reveals the seasonal and spatial variation of transport and chemical processes in the UT and LMS

Analysis of MLS CO in the Lowermost Stratosphere

The Lowermost Stratosphere (LMS):

-- the 380K surface above (~100 hPa)
-- the tropopause below

The extratropical tropopause layer (ExTL) has PV ≤ ~5.



Aura MLS CO (v2.2), especially the 215 hPa observations. There is a ~2X bias, but it's good for structures and cycles as long as we don't combine with other levels. Will use MLS temperature too.

MOPITT V4 CO columns – most sensitive to 1000-800 hPa

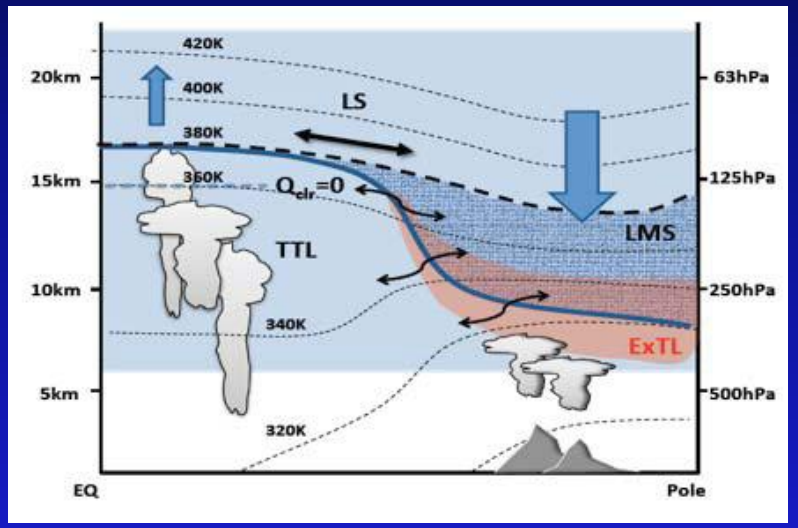
AIRS CO columns – more sensitive to mid-tropospheric CO

Potential Vorticity – from the GEOS data assimilation system.

MLS CO Data Analysis

Calculate monthly mean CO in the extratropics

- latitudes 40-80 in each hemisphere
- 215 hPa MLS CO, *sometimes in the ExTL, sometimes in the LMS*
- for LMS, select Theta <380K and PV>5
- for ExTL, select PV < 5



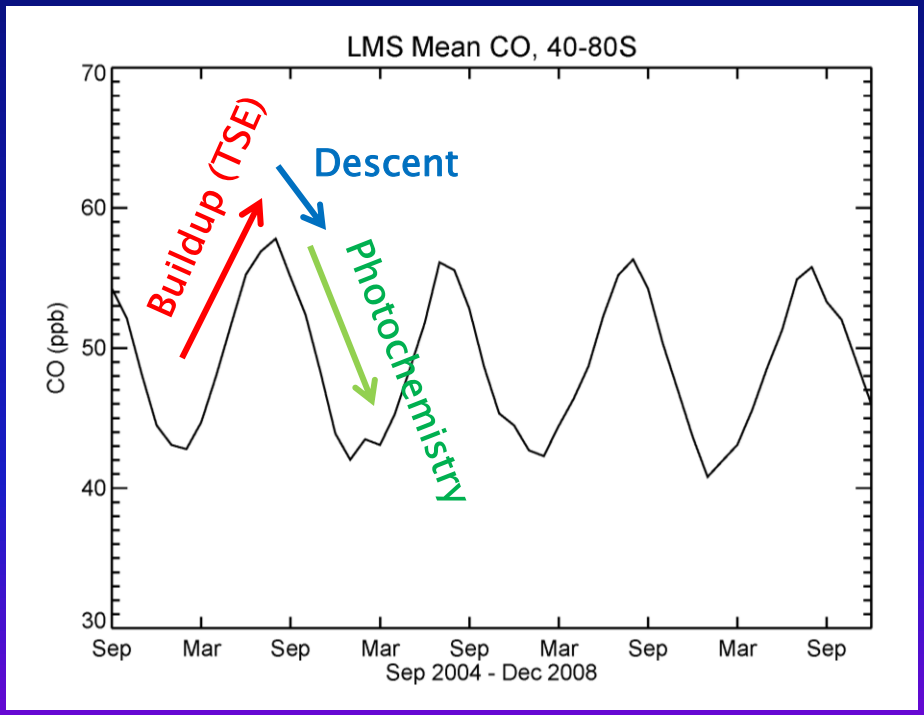
The Results: area-weighted monthly mean CO for ExTL and LMS from Sept 2004-Dec 2008 (all latitudes are well-represented with these criteria)

Note: MLS 215 hPa obs are known to be ~2X too high. All figures are scaled by 0.5. **Mixing ratios shown are not exact!**

MLS CO: Seasonally varying composition of the LMS

This is the seasonal cycle of LMS CO in the Southern Hemisphere. This is as simple as it gets.

- The same from year to year.
- CO builds up late summer thru mid-winter via horizontal transport from tropical UT (TSE).
- Photochemistry is negligible Apr-Sep (fall/winter)
- CO decreases from Sep to Feb (spr/sum) due late winter descent followed by photochemical loss.



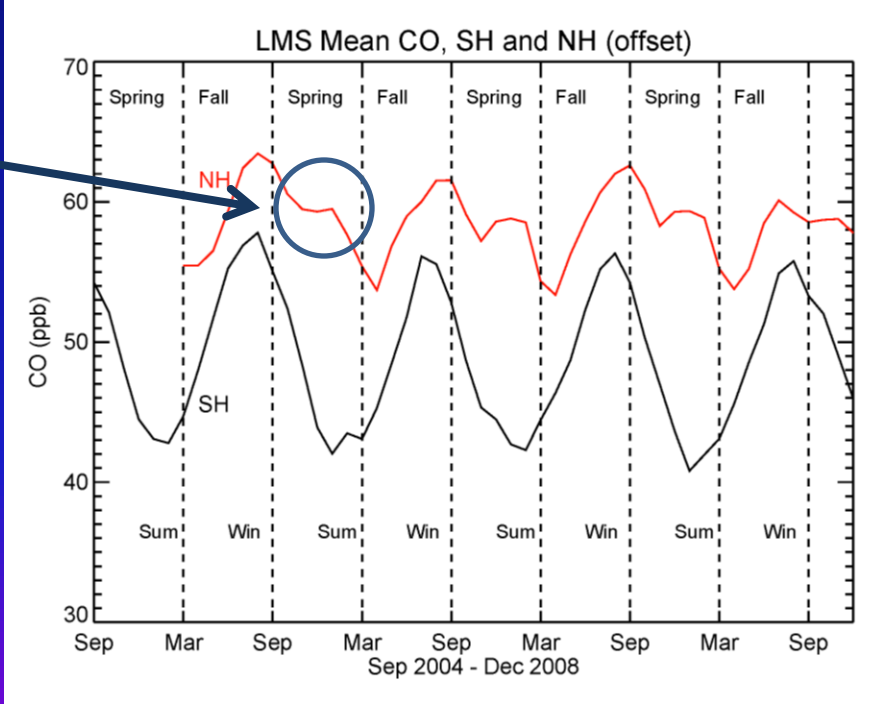
SH Cycle = Brewer Dobson Circulation + TSE + seasonal chemistry

MLS CO: Seasonally varying composition of the LMS

Both hemispheres have the same basic features:
Decline (descent in late winter), photochemical loss in spring and summer, buildup from transport in fall through midwinter.

Except – NH a big bump from May–August every year.

Asian monsoon transport!



The NH cycle amplitude is ~5 ppb less than the SH.

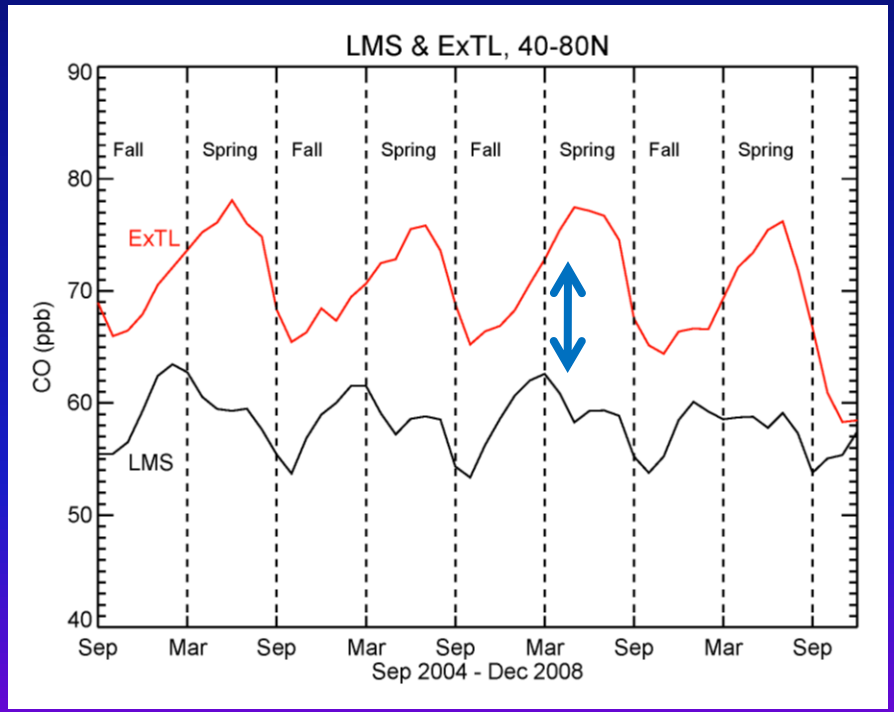
Asian monsoon is able to raise the mean CO of the LMS.

NH Cycle = BD Circulation + TSE + seasonal chemistry + monsoon transport

MLS CO: The NH LMS and the ExTL

- The cycles in the LMS and ExTL are not the exactly same – different processes at work.
- Both show photochemical loss from Aug–Oct.
- Both show buildup from Oct to Feb.
- Both show monsoon effects (JJA)
- The LMS cycle declines in Apr/May (descent). ExTL is more tropospheric and may reflect emissions in these months.

The cycles differ in early spring

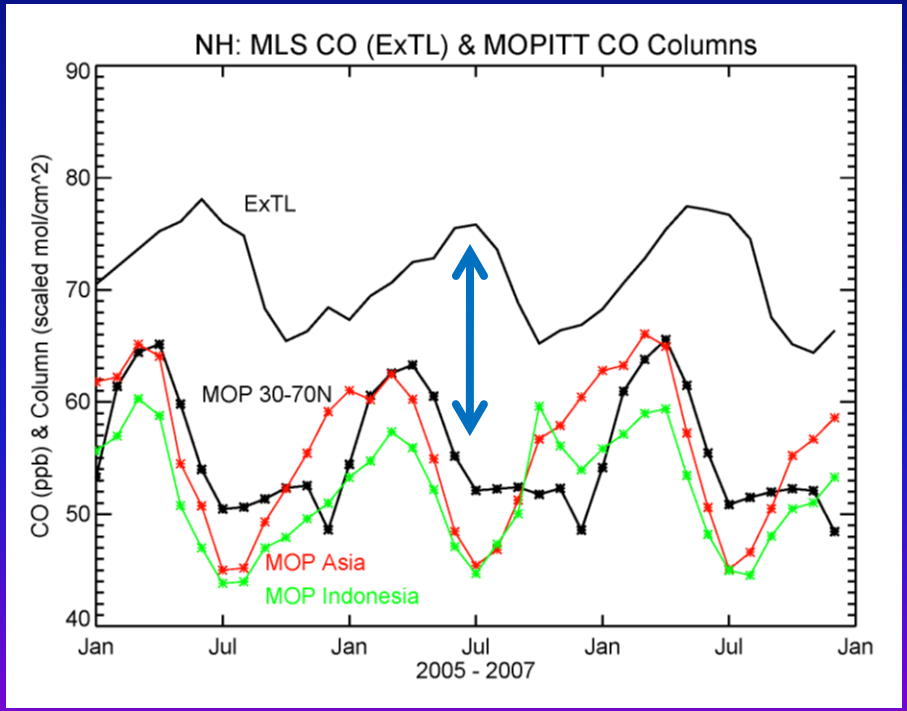


MOPITT CO: What's going on near the surface?

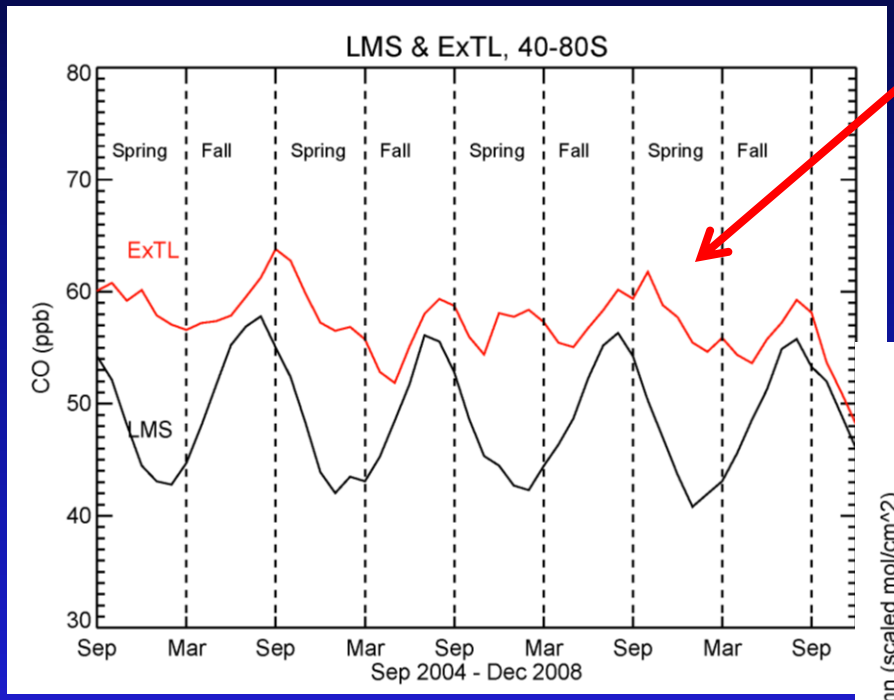
We can compare the MLS cycle near the tropopause (ExTL) with the cycle of the total column CO. The MOPITT column is most sensitive to 1000-800 hPa, so we expect it to have a strong contribution from surface sources.

MOPITT columns show large NH sources from Jan-Apr, but the ExTL CO increases in MJJ while the MOPITT column decreases.

High CO in the ExTL reflects increasing sources from fall until April, but high CO in MJJ is probably coming from the Asian monsoon.

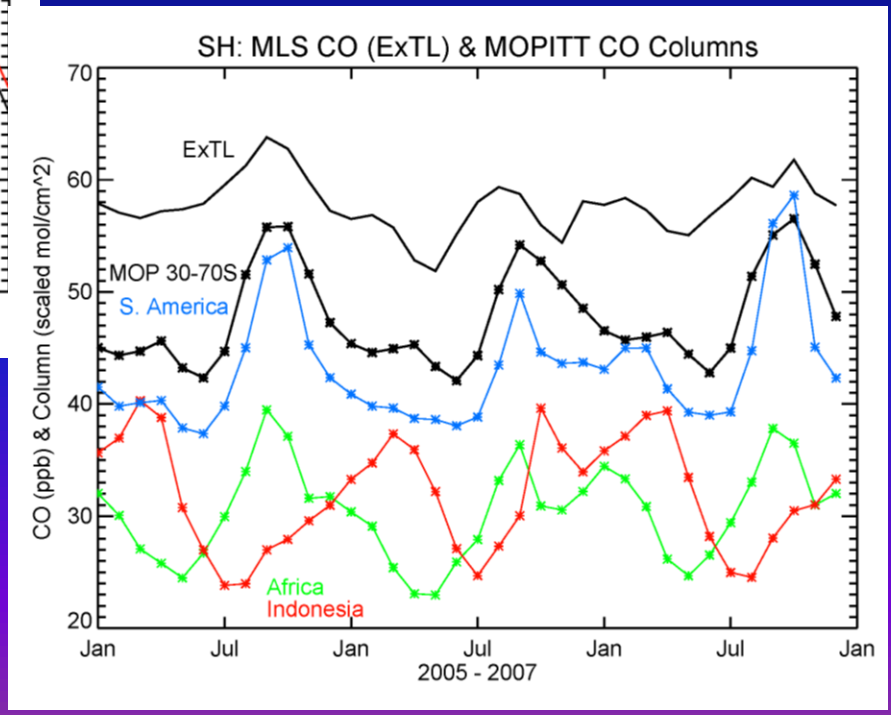


MOPITT CO: Southern Hemisphere?



The ExTL cycle is small and bumpy.

The LMS cycle is larger than the ExTL cycle. LMS is not strongly influenced by the troposphere.



MOPITT columns suggest that the SH ExTL cycle comes from S. American emissions, but Indonesian emissions may play a role in the Jan/Feb bumps.

What we have learned about UT/LMS processes…

Processes in the Lowermost Stratosphere:

- Simple cycle of descent, photochemical loss, and source gas buildup in both hemispheres. *Stratospheric*.
- NH adds a twist to the cycle with a contribution of high CO from the Asian Monsoon (MJJA).

Processes affecting the Extratropical Tropopause Layer (ExTL):

- The cycle is generally not like the LMS cycle, but photochemical loss is important.
- Mid-latitude surface sources have large impact.
- Tropical sources may play a role in the (small) SH ExTL cycle.
- The NH cycle shows a MJJA source that does *not* appear in the (near surface) column: Asian Monsoon transport.

How well can models produce CO seasonal cycles in the LMS and ExTL?

If we have a model with…

CO emissions sources
full tropospheric and stratospheric chemistry
reasonable meteorological fields

…can we get a realistic CO simulation?

If not, can we tell which processes are misrepresented?

MLS/MOPITT CO analysis results will be used to evaluate two Global Modeling Initiative (GMI) chemistry and transport model (CTM) simulations.

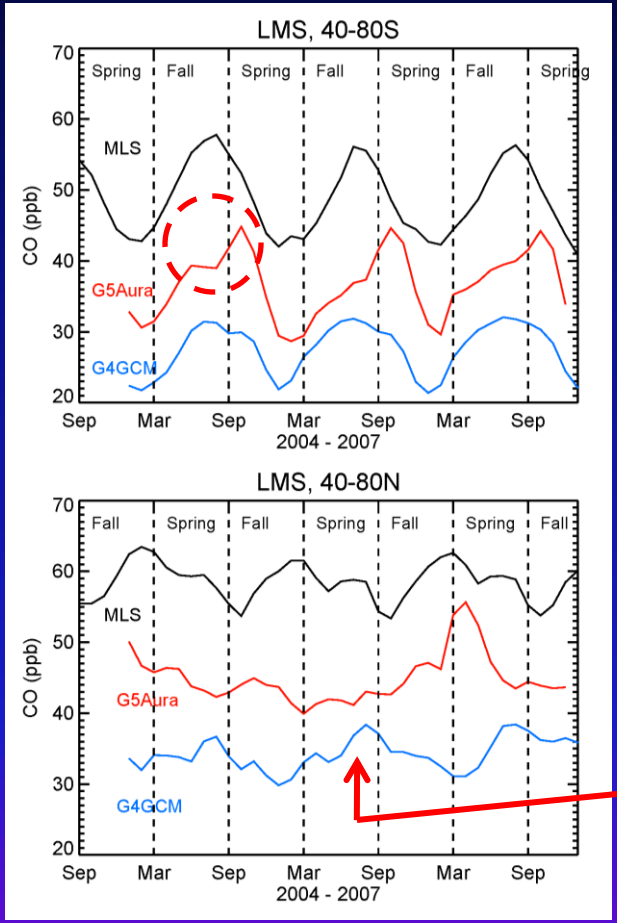
- GEOS-4 GCM met fields ('G4GCM')
- GEOS-5.1 assimilated met fields ('G5Aura')
- Same chemistry, same horizontal resolution, and similar emissions.

Compare the Models' LMS with MLS CO

G5Aura (red):

SH: Cycle has ok basic shape, but lacks CO from June-Sep. Problem with TSE or strat descent?

NH: Not much of a cycle at all. Monsoon transport doesn't affect composition. No clear signal of loss in spring/summer.



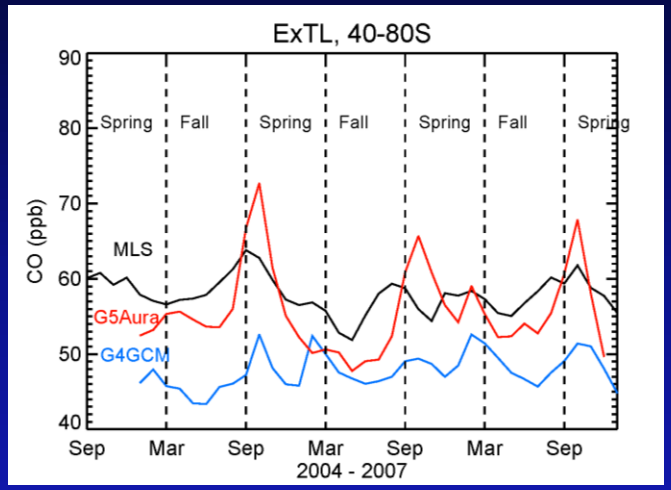
G4GCM (blue):

SH: Cycle phase is ok. Maximum is blunted, but tropical CO looks good? TSE or strat descent?

NH: Not too pretty, although every summer there is a bump up – monsoon transport has an impact in the LMS.

Both models have a tropical UT cycle very similar to MLS (not shown), so problems with LMS cycle may be from TSE from tropics to LMS.

Compare the Models' ExTL with MLS CO



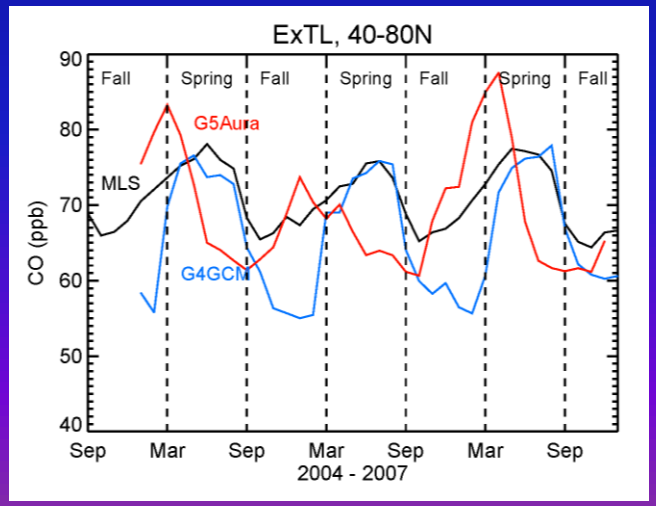
Tropopause – Southern Hemisphere

G4GCM has similar features to MLS.

G5Aura's CO bumps don't line up well with timing or magnitude of MLS. Mean CO is higher than G4GCM.

Tropopause – Northern Hemisphere

G4GCM doesn't show Oct-Feb buildup, but captures the rest of the year (including monsoon signal).
G5Aura does a better job with the Oct-Feb buildup but shows no high CO in MJJA from monsoon transport.

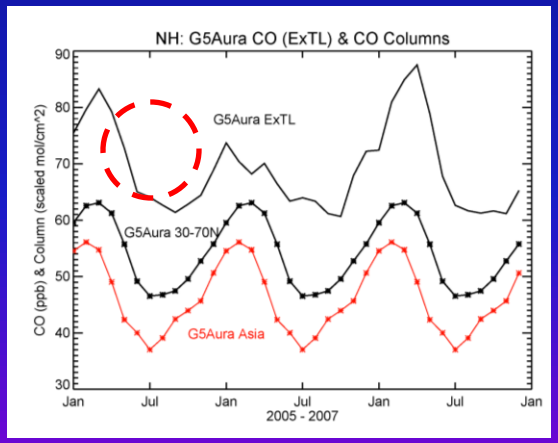


How do surface sources affect the ExTL in the NH?

G5Aura :

Asian emissions drive the ExTL cycle. They decline in March, sooner than observed, but generally look like MOPITT.

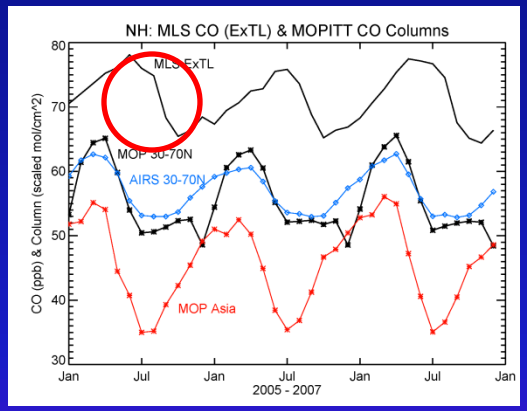
High CO MJJA is not seen in the columns or aloft.



MOPITT, AIRS, & MLS CO:

Asian emissions are a major component of the ExTL cycle.

Large CO in ExTL from May-Aug is not seen in columns.

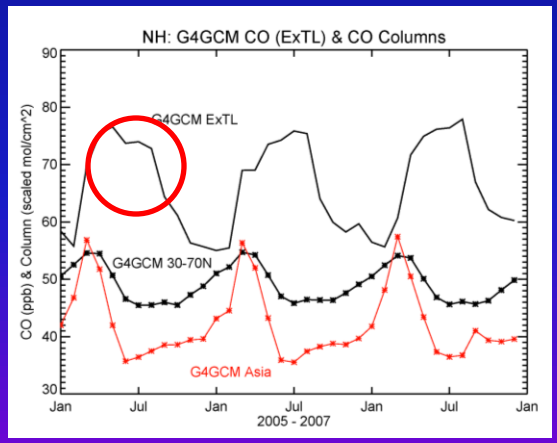


Thanks to Leonid Yurganov (UMBC) for AIRS data.

G4GCM:

Asian emissions contribute to the ExTL cycle, but are too low for much of the year.

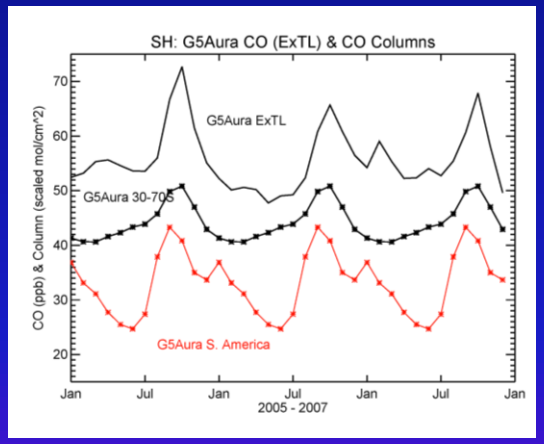
Large CO in the ExTL from Apr-Aug is not seen in the columns.



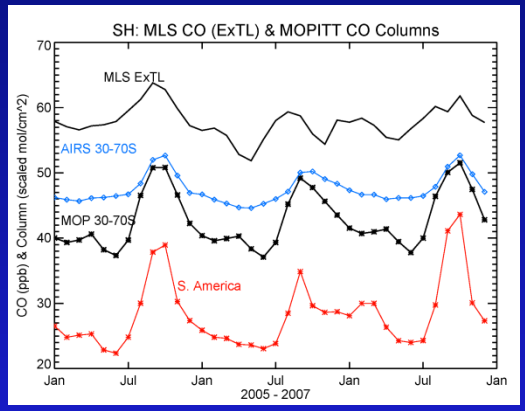
Models' Asian emissions are too low in March and April. G4GCM Asian emissions are quite low in fall.

How do surface sources affect the ExTL in the SH?

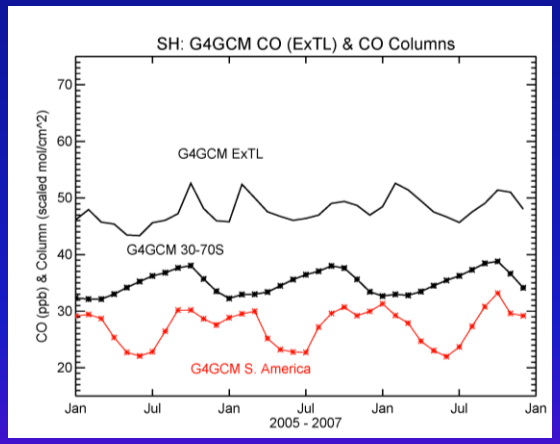
G5Aura :
So. American emissions are important to the ExTL cycle.



MOPITT, AIRS & MLS CO:
MLS ExTL shows a large contribution from So. American emissions.



G4GCM:
So. American are important to the EXTL cycle, but they don't look like MOPITT.



Models show same *behavior* as observations: SH ExTL cycle is strongly influenced by So. American emissions.

1. What have we learned about the processes affecting CO in the LMS and ExTL?

The Lowermost Stratosphere looks, well, stratospheric.

The LMS cycle is a balancing act between:

Descent + Trop–Strat–Exchange + chemistry (+ monsoon)

…and it shows very little interannual (IA) variation. This suggests that IA variation in sources does not *directly* affect composition here.

The Tropopause Layer is much more connected with the troposphere.

The observed ExTL cycles are strongly influenced by low/midlatitude CO sources (So. America and SE Asia).

Asian monsoon transport is clearly present.

2. What have we learned about our ability to simulate the relevant processes?

The Modeled LMS…

This is a tricky place to simulate CO because 3-4 different processes influence CO. If they don't have the right magnitude and seasonal behavior, the cycle is a mess.

The Modeled ExTL…

The tropopause layers (NH and SH) do show a good connection to emissions from the low/midlatitudes. If emissions are significantly off we should see this in the ExTL cycle.

The Modeled CO Columns…

MOPITT (and AIRS) columns give us information on regional sources (e.g, Asia, Indonesia, So. America) that we can use to improve our models' emission inputs. This comparison identified low Asian emissions as the reason for low fall/winter CO in the LMS and ExTL.